MICRO-PUMP DRIVEN BY PHASE CHANGE OF A FLUID

BACKGROUND OF THE INVENTION

1.   Field of the Invention

[0001]   The present invention relates to a micro-pump.   More particularly, the present invention relates to a micro-pump driven by a phase change of a fluid.

2.   Description of the Related Art

[0002]   Due to recent, significant developments in micro-machining technology, micro electro mechanical systems (MEMS) with a variety of functions have been developed.   MEMS devices have many advantages in terms of their size, manufacturing costs, and reliability, and thus, research has been vigorously carried out on ways to apply MEMS devices to a variety of fields.

[0003]   Currently, research is being conducted on a method of implementing a compact-sized fluid system onto a single chip.   Such research invigorates various attempts to develop techniques regarding a microstructure, such as a micro-pump or a valve, which can control the flow of a very small amount of fluid.

[0004]   FIGS. 1A and 1B illustrate cross-sectional views of a conventional micro-pump having check valves.   Referring to FIGS. 1A and 1B, the conventional micro-pump is driven by a piezoelectric body 12 attached to an

upper film of a pumping chamber 10.   A fluid entrance 14 and a fluid exit 16 are connected to the pumping chamber 10, and first and second check valves 15 and 17 are provided at the interface between the fluid entrance 14 and the pumping chamber 10 and at the interface between the fluid exit 16 and the pumping chamber 10, respectively.   As shown in FIG. 1A, when the piezoelectric body 12 is transformed due to a voltage applied thereto, the volume of the pumping chamber 10 increases.   Then, the second check valve 17 is shut and the first check valve 15 is opened so that a fluid can be supplied into the pumping chamber 10 through the fluid entrance 14.   As shown in FIG. 1B, when the piezoelectric body 12 is transformed so that the volume of the pumping chamber 10 decreases, the first check valve 15 is shut, and the second check valve 17 is opened.   Accordingly, a small amount of fluid is discharged through the fluid exit 16.

[0005]   In the conventional micro-pump of FIGS. 1A and 1B, the check valves 15 and 17, which induce the flow of a fluid in one direction, are intended to operate in a tiny structure.   Pumps and valves used in MEMS devices, in particular, are required to have a very small size.   Therefore, due to the sizes thereof, the check valves 15 and 17 are not suitable for application in MEMS devices.   Even if the check valves 15 and 17 are implemented in a MEMS device, it is difficult to guarantee the durability of the check valves 15 and 17 for any required predetermined time period.   In addition, due to the

mass inertia of the check valves 15 and 17, the check valves 15 and 17 may not operate well at high frequencies.

[0006]   FIG. 2 illustrates a cross-sectional view of another conventional micro-pump.   Referring to FIG. 2, the conventional micro-pump does not have movable elements as the check valves 15 and 17 of FIGS. 1A and 1B. Rather, the conventional micro-pump of FIG. 2 includes a pair of fluid passages 22 and 23, which are pyramid-shaped.   The fluid passages 22 and 23 are connected to a lower part of a pumping chamber 20 so that they extend along different directions.   A piezoelectric body 21 is installed at an upper film of the pumping chamber 20 as a driving means.   The fluid passage 22 has such a structure that a cross-sectional area thereof decreases along a direction toward the pumping chamber 20.   The fluid passage 23 has such a structure that a cross-sectional area thereof increases along the direction toward the pumping chamber 20.

[0007]   If the fluid passage 22 or 23 is formed with a relatively large inclination angle of about 50 - 70°, flux resistance in a direction along which the cross-sectional area of the fluid passage 22 or 23 decreases is smaller than flux resistance in a direction along which the cross-sectional area of the fluid passage 22 or 23 increases.   Accordingly, fluids respectively passing through the fluid passages 22 and 23 are affected by different levels of flux resistance due to volume variations in the pumping chamber 20 caused by

vibration of the piezoelectric body 21. The conventional micro-pump of FIG. 2 enables a net flow rate in a direction in which fluid is pumped out, without the need for check valves.

[0008]   FIGS. 3A and 3B illustrate cross-sectional views of still another conventional micro-pump.

[0009]   The conventional micro-pump of FIGS. 3A and 3B does not have valves. Rather, the conventional micro-pump of FIGS. 3A and 3B includes a pair of fluid passages, i.e., a fluid exit 33 and a fluid entrance 34, having cross-sectional areas that vary along a direction in which a fluid is pumped. The fluid exit 33 and the fluid entrance 34 are connected to opposite sides of a pumping chamber 30, and a piezoelectric membrane 32 is provided on the pumping chamber 30 as a driving means. A cross-sectional area of the fluid entrance 34 increases in a direction toward the pumping chamber 30, while a cross-sectional area of the fluid exit 33 decreases in a direction toward the pumping chamber 30. If the fluid passages 33 and 34 are formed with a relatively small inclination angle of about 15 - 30°, flux resistance in a direction of increasing cross-sectional area of the fluid passages 33 and 34 is smaller than flux resistance in a direction of decreasing cross-sectional area of the fluid passages 33 and 34. Therefore, as shown in FIG. 3A, when a fluid is pumped into the pumping chamber 30 due to a transformation of the piezoelectric membrane 32, an amount of fluid

passing through the fluid entrance 34 is larger than an amount of fluid passing through the fluid exit 33. However, as shown in FIG. 3B, when the fluid is discharged from the pumping chamber 30, the amount of fluid passing through the fluid exit 33 is much larger than the amount of fluid passing through the fluid entrance 34. Therefore, the conventional micro-pump of FIGS. 3A and 3B generates a net flow rate in a direction in which the fluid is pumped due to a difference between the flux resistance in the direction of increasing cross-sectional area of the fluid passages 33 and 34 and the flux resistance in the direction of decreasing cross-sectional area of the fluid passages 33 and 34.

[0010]   The above-mentioned conventional micro-pumps generate a net flow rate by taking advantage of a variation of the volume of a pumping chamber caused by vibrations of a piezoelectric body. However, the piezoelectric body, having a complex structure, is relatively difficult to manufacture. In addition, in order to increase a pumping flow rate, the area of the piezoelectric body should be increased. However, given the current level of technology, it is very difficult and very expensive to increase the area of the piezoelectric body. A pumping flow rate can be increased by increasing the volume of a pumping chamber. In this case, however, the degree to which an upper film of the pumping chamber is transformed due to vibrations of the

piezoelectric body should be enlarged, which may result in a high possibility of serious damage to the upper film.

SUMMARY OF THE INVENTION

[0011]   In an effort to solve these and other problems, the present invention provides a micro-pump having a relatively simple structure, but which shows enhanced durability and high pumping efficiency without the need for movable elements by pumping out a fluid supplied into a pumping chamber by simply taking advantage of a phase change of the fluid.

[0012]   Accordingly, it is a feature of an embodiment of the present invention to provide a micro-pump including a pumping chamber having a predetermined inner space to be filled with a fluid, at least one fluid entrance and at least one fluid exit, which are connected to the pumping chamber, a heating element provided at one side of the pumping chamber to generate bubbles in the pumping chamber by heating the fluid, and electrodes for applying current to the heating element, wherein the fluid is made to flow into or out of the pumping chamber by expansion and contraction of the bubbles, and wherein a cross-sectional area of at least one of the fluid entrance and the fluid exit varies along a direction in which the fluid flows.

[0013]   Preferably, the cross-sectional area of the fluid entrance decreases in a direction toward the pumping chamber, and the cross-sectional area of the fluid exit increases in a direction toward the pumping chamber.

[0014] Preferably, the fluid entrance and the fluid exit are formed to have an inclination angle of at least about 50°.

[0015] Preferably, the cross-sectional area of the fluid entrance increases in a direction toward the pumping chamber, and the cross-sectional area of the fluid exit decreases in a direction toward the pumping chamber.

[0016] Preferably, the fluid entrance and the fluid exit are respectively formed to have an inclination angle of about 30° or less.

[0017] Preferably, the fluid entrance is provided at one side of the pumping chamber and the fluid exit is provided at an opposite side of the pumping chamber to face the fluid entrance.

[0018] Preferably, the fluid entrance and the fluid exit each have a pyramid shape.

[0019] Preferably, the fluid entrance and the fluid exit each have a uniform height and a width that varies in a direction in which the fluid flows.

[0020] Preferably, the pumping chamber and the heating element each have a rectangular shape.

[0021] Preferably, the pumping chamber and the heating element each have a circular shape.

[0022] Preferably, the heating element is formed of a resistive heating material.

[0023]   The micro-pump may further include a substrate in which the pumping chamber, the fluid entrance, and the fluid exit are formed.

[0024]   The micro-pump may further include an insulation layer formed on the substrate, wherein the insulation layer constitutes an upper wall of the pumping chamber, and the heating element and the electrodes are formed on the insulation layer.

[0025]   The micro-pump may further include a passivation layer having insulation characteristics formed on the heating element and the electrodes.

[0026]   The micro-pump may further include a heat dissipation layer formed on the passivation layer for dissipating heat, wherein the heat dissipation layer is connected to the substrate.

[0027]   Preferably, the heat dissipation layer is formed of a metal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028]   The above and other features and advantages of the present invention will become more apparent to those of ordinary skill in the art by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

[0029]   FIGS. 1A and 1B respectively illustrate cross-sectional views of a fluid supply mode and a fluid pumping mode of a conventional micro-pump;

[0030]   FIG. 2 illustrates a cross-sectional view of another conventional micro-pump;

[0031]   FIGS. 3A and 3B respectively illustrate cross-sectional views of a fluid

supply mode and a fluid pumping mode of still another conventional

micro-pump;

[0032]   FIG. 4A illustrates a plan view of a micro-pump according to a first

embodiment of the present invention;

[0033]   FIG. 4B illustrates a cross-sectional view of the micro-pump according

to the first embodiment of the present invention taken along line A – A' of

FIG. 4A;

[0034]   FIG. 4C illustrates a cross-sectional view of the micro-pump according

to the first embodiment of the present invention taken along line B – B' of

FIG. 4A;

[0035]   FIGS. 5A and 5B respectively illustrate cross-sectional views of a fluid

pumping mode and a fluid supply mode of the micro-pump according to the

first embodiment of the present invention;

[0036]   FIG. 6A illustrates a plan view of a micro-pump according to a second

embodiment of the present invention;

[0037]   FIG. 6B illustrates a cross-sectional view of the micro-pump according

to the second embodiment of the present invention taken along line C – C' of

FIG. 6A;

[0038]   FIGS. 7A and 7B respectively illustrate cross-sectional views of a fluid

pumping mode and a fluid supply mode of the micro-pump according to the

second embodiment of the present invention; and

[0039]   FIGS. 8A through 8C are graphs illustrating characteristics of a

micro-pump according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0040]   Korean Patent Application No. 2003-2727, filed on January 15, 2003,

and entitled: "Micro-Pump Driven by Phase Change of Fluid," is incorporated

by reference herein in its entirety.

[0041]   The present invention will now be described more fully hereinafter

with reference to the accompanying drawings, in which exemplary

embodiments of the invention are shown.   The invention may, however, be

embodied in different forms and should not be construed as limited to the

embodiments set forth herein.   Rather, these embodiments are provided so

that this disclosure will be thorough and complete, and will fully convey the

scope of the invention to those skilled in the art.   In the drawings, the

thickness of layers and regions are exaggerated for clarity.   Like reference

numerals refer to like elements throughout.

[0042]   FIG. 4A illustrates a plan view of a micro-pump according to a first

embodiment of the present invention.   FIG. 4B illustrates a cross-sectional

view of the micro-pump according to the first embodiment of the present

invention taken along line A – A' of FIG. 4A. FIG. 4C illustrates a cross-sectional view of the micro-pump according to the first embodiment of the present invention taken along line B – B' of FIG. 4A.

[0043]   Referring to FIGS. 4A through 4C, a micro-pump according to a first embodiment of the present invention includes a pumping chamber 112, which has a predetermined inner space so that it can be filled with a fluid, a fluid entrance 113 and a fluid exit 114, which are connected to the pumping chamber 112, a heating element 130, which is provided at one side of the pumping chamber 112, and electrodes 151 and 152, which apply current to the heating element 130.

[0044]   As shown in FIG. 4A, the pumping chamber 112 has a rectangular shape, and the predetermined inner space of the pumping chamber 112 has a rectangular hexahedral shape. In the pumping chamber 112, a driving force is applied to a fluid supplied into the pumping chamber 112 via the fluid entrance 113 to thereby discharge the fluid through the fluid exit 114.

[0045]   The fluid entrance 113, which is provided between an inlet manifold 115 and the pumping chamber 112, supplies a fluid from the inlet manifold 115 into the pumping chamber 112. The fluid exit 114, which is provided between an outlet manifold 116 and the pumping chamber 112, discharges a fluid from the pumping chamber 112 to the outlet manifold 116. As shown in FIGS. 4A through 4C, there may be one fluid entrance 113 and

one fluid exit 114 provided to the micro-pump. Alternatively, in order to increase a flow rate, a plurality of fluid entrances and a plurality of fluid exits may be provided to the micro-pump. The fluid entrance 113 is provided at one side of the pumping chamber 112 and the fluid exit 114 is provided at an opposite side of the pumping chamber 112 so that the fluid exit 114 faces the fluid entrance 113. However, the fluid entrance 113 and the fluid exit 114 may be arranged differently. For example, the fluid entrance 113 and the fluid exit 114 may be arranged together at one side of the pumping chamber 112 or under the pumping chamber 112.

[0046] The fluid entrance 113 has a decreasing cross-sectional area in a direction toward the pumping chamber 112, while the fluid exit 114 has an increasing cross-sectional area in a direction toward the pumping chamber 112. In addition, the fluid entrance 113 and the fluid exit 114 preferably have an inclination angle θ of at least about 50°, for example, an inclination angle of about 50 - 70°. Then, flux resistance affecting a fluid passing through the fluid entrance 113 and the fluid exit 114 varies depending on the flow direction of the fluid. More specifically, flux resistance in a direction in which the cross-sectional area of the fluid entrance 113 and the cross-sectional area of the fluid exit 114 decreases is smaller than flux resistance in a direction in which the cross-sectional area of the fluid entrance 113 and the cross-sectional area of the flow exit 114

increases. Due to a difference between the flux resistance in the direction of decreasing cross-sectional area of the fluid entrance 113 and the fluid exit 114 and the flux resistance in the direction of increasing cross-sectional area of the fluid entrance 113 and the flow exit 114, a net flow rate can be generated in a direction in which the fluid is pumped without the need for check valves, which will be described more fully later.

[0047]   In order to satisfy the above-mentioned requirements, the fluid entrance 113 and the fluid exit 114 may have a pyramid shape, as shown in FIGS. 4A and 4B, so that the cross-sectional areas thereof decrease along the direction in which the fluid is pumped. Alternatively, each of the fluid entrance 113 and the fluid exit 114 may have a uniform height but a decreasing width along the direction in which the fluid is pumped. However, the fluid entrance 113 and the fluid exit 114 may have a different shape, such as a polygonal or circular cross-section, provided they meet the above-mentioned requirements.

[0048]   Both the fluid entrance 113 and the fluid exit 114 have been described so far as having a varying cross-sectional area along a certain direction. However, it is possible to achieve a net flow rate by forming only one of the fluid entrance 113 and the fluid exit 114 to have a varying cross-sectional area along a certain direction.

[0049]   The pumping chamber 112, the fluid entrance 113, the fluid exit 114,

and the inlet and outlet manifolds 115 and 116 may be formed by

micro-machining a substrate 110 in a variety of ways.   Preferably, the

pumping chamber 112, the fluid entrance 113, the fluid exit 114, and the inlet

and outlet manifolds 115 and 116 are formed by etching the surface of the

substrate 110 to a predetermined depth, in which case the fluid entrance 113

and the fluid exit 114 may be formed on the substrate 110 to a

predetermined depth, to be connected to an upper portion of the pumping

chamber 112.

[0050]   An insulation layer 120 is formed on the substrate 110, and forms an

upper wall of the pumping chamber 112.   The heating element 130 is

formed on the insulation layer 120.   The heating element 130 generates

bubbles in the pumping chamber 112 by heating the fluid in the pumping

chamber 112.   Expansions and contractions of the bubbles cause the fluid

to flow.   The heating element 130 may be formed of a resistive heating

element, such as an alloy of tantalum and aluminium or tantalum nitride.   As

shown in FIG. 4A, the heating element 130, like the pumping chamber 112,

preferably has a rectangular shape.   The heating element 130, however,

may have a different shape.

[0051]   A first passivation layer 140, which has insulation characteristics, is

formed on the heating element 130 and the insulation layer 120, and the

electrodes 151 and 152 are formed on the first passivation layer 140.   The

electrodes 151 and 152 are connected to the heating element 130 at either

side of the heating element 130 through a contact hole C_1 formed in the first

passivation layer 140.

[0052]   A second passivation layer 160, which has insulation characteristics,

is formed on the first passivation layer 140 and the electrodes 151 and 152,

and a heat dissipation layer 170 may be formed on the second passivation

layer 160.   The heat dissipation layer 170 is connected to the substrate 110

through a second contact hole C_2, which is formed through the first and

second passivation layers 140 and 160 and the insulation layer 120.   The

heat dissipation layer 170 is provided for dissipating heat of the heating

element 130 or other elements near the heating element 130 to the

substrate 110 or to the outside.   The heat dissipation layer 170 may be

formed of a metal having superior heat conductivity.

[0053]   Hereinafter, a process of pumping a fluid in the micro-pump according

to the first embodiment of the present invention will be described in greater

detail with reference to FIGS. 5A and 5B.   FIGS. 5A and 5B respectively

illustrate cross-sectional views of a fluid pumping mode and a fluid supply

mode of the micro-pump according to the first embodiment of the present

invention.

[0054]   Referring to FIG. 5A, the pumping chamber 112 is filled with a

fluid 180.   When a pulse-type current signal is applied to the heating

element 130 via the electrodes 151 and 152, the heating element 130

generates heat to heat the fluid 180 in the pumping chamber 112 via the

insulation layer 120.   When the fluid 180 is heated to a predetermined

temperature or higher, the fluid 180 boils, and accordingly, a bubble 190 is

generated.   Since the bubble 190 is in a gas phase with high pressure, it

expands pushing out nearby fluid 180.   Due to the expansion of the

bubble 190, the fluid 180 in the pumping chamber 112 is discharged to the

outlet manifold 116 through the fluid exit 114, during which the current signal

applied to the heating element 130 is removed.   The expansion of the

bubble 190 also generates a flow rate in the opposite direction by causing

the fluid 180 to flow to the inlet manifold 115 through the fluid entrance 113.

Since flux resistance in a direction of decreasing cross-sectional area of the

fluid entrance 113 and the fluid exit 114 is smaller than flux resistance in a

direction of increasing cross-sectional area of the fluid entrance 113 and the

fluid exit 114, the amount of fluid discharged through the fluid exit 114 is

much larger than the amount of fluid discharged through the fluid

entrance 113.

[0055]   Referring to FIG. 5B, the bubble 190 contracts and disappears after

expanding to its maximum size.   Then, pressure affects the pumping

chamber 112 in a direction from outside the pumping chamber 112 to the inside of the pumping chamber 112. Accordingly, the fluid flows into the pumping chamber 112 through both the fluid entrance 113 and the fluid exit 114. In this case, flux resistance at the fluid entrance 113 is smaller than flux resistance at the fluid exit 114. Thus, the amount of fluid flowing into the pumping chamber 112 through the fluid entrance 113 is much larger than the amount of fluid flowing into the pumping chamber through the fluid exit 114. During this process, heat generated by the heating element 130 to generate the bubble 190 is dissipated to the substrate 110 and to the outside via the heat dissipation layer 170. Due to the existence of the heat dissipation layer 170, heat can be more quickly dissipated. Thus, a cycle of expansion and contraction that the bubble 190 undergoes becomes shorter, and the driving frequency of the micro-pump is increased.

[0056]   As described above, when the bubble 190 expands, the amount of fluid 180 discharged from the pumping chamber 112 through the fluid exit 114 is much larger than the amount of fluid 180 discharged from the pumping chamber 112 through the fluid entrance 113. When the bubble 190 contracts, however, the amount of fluid 180 flowing into the pumping chamber 112 through the fluid entrance 113 is much larger than the amount of fluid 180 flowing into the pumping chamber 112 through the fluid exit 114. Therefore, if the bubble 190 repeatedly undergoes a cycle of

expansion and contraction with a predetermined frequency, a net flow rate in a direction from the fluid entrance 113 to the pumping chamber 112 to the fluid exit 114 can be generated, and desired pumping effects can be achieved.

[0057]   In the micro-pump according to the first embodiment of the present invention, the heating element 130 provides a driving force for pumping the fluid 180, and the fluid entrance 113 and exit 114 serve as dynamic passive valves.   Thus, there is no need to additionally provide movable elements, such as a piezoelectric body or check valves, to the micro-pump.   Therefore, it is possible to realize a micro-pump having a relatively simple structure and improved durability.   In addition, it is possible to increase a pumping flow rate by increasing the area or caloric power of the heating element 130 provided at one side of the pumping chamber 112.

[0058]   FIG. 6A illustrates a plan view of a micro-pump according to a second embodiment of the present invention.   FIG. 6B illustrates a cross-sectional view of the micro-pump according to the second embodiment of the present invention taken along line C – C' of FIG. 6A.   In FIG. 6A, only features of the present invention that are different from their counterparts in the first embodiment of the present invention are illustrated for convenience of the drawing.   In addition, the second embodiment of the present invention is the same as the first embodiment of the present invention except in a shape of a

pumping chamber 212, a heating element 230, and fluid passages 213 and 214. Thus, the only differences between the first and second embodiments of the invention will be described in the following paragraphs with respect to FIGS. 6A and 6B.

[0059]   Referring to FIGS. 6A and 6B, a micro-pump according to a second embodiment of the present invention includes the pumping chamber 212, which has a circular shape. An inner space of the pumping chamber 212 may have a hemispherical or cylindrical shape. Accordingly, the heating element 230 preferably has a circular shape, as shown in FIG. 6A. The fluid passages 213 and 214, i.e., a fluid entrance 213 and a fluid exit 214, are formed to extend relatively very long. Thus, it is difficult to form the fluid passages 213 and 214 to have a relatively large inclination angle. Therefore, in the second embodiment of the present invention, unlike in the first embodiment, the fluid entrance 213 has an increasing cross-sectional area in a direction toward the pumping chamber 212, while the fluid exit 214 has a decreasing cross-sectional area in a direction toward the pumping chamber 212. The fluid entrance 213 and the fluid exit 214 are preferably formed to have a relatively small inclination angle θ of about 15 - 30°. Due to the existence of the fluid passages 213 and 214, flux resistance in a direction of gradually increasing cross-sectional area of the fluid passages 213 and 214 is smaller than flux resistance in a direction of

gradually decreasing cross-sectional area of the fluid passages 213 and 214, which will be described more fully later.

[0060]   The fluid passages 213 and 214 may have different shapes provided they meet the above-mentioned requirements.   In the present embodiment, like in the previous embodiment, it is possible to form only one of the fluid passages 213 and 214 to have a gradually decreasing or gradually increasing cross-sectional area.

[0061]   Preferably, the pumping chamber 212, the fluid entrance 213, the fluid exit 214, and inlet and outlet manifolds 215 and 216 are formed by etching a surface of a substrate 210 to a predetermined depth, in which case the fluid passages 213 and 214 are preferably formed to have a uniform height but an increasing width in a direction along which a fluid is pumped.

[0062]   An insulation layer 220, a heating element 230, a first passivation layer 240, electrodes 251 and 252, a second passivation layer 260, and a heat dissipation layer 270 formed on the substrate 210 are the same as their counterparts in the first embodiment of the present invention, and thus their description will not be repeated.

[0063]   Hereinafter, operation of the micro-pump according to the second embodiment of the present invention will be described in greater detail with reference to FIGS. 7A and 7B.   FIG. 7A illustrates a fluid pumping mode, and FIG. 7B illustrates a fluid supply mode.

[0064]   Referring to FIG. 7A, a pulse-type current signal is applied to the heating element 230 via the electrodes 251 and 252.   Then, heat is generated by the heating element 230.   The generated heat heats a fluid 280 inside the pumping chamber 212 so that a bubble 290 is generated. Due to expansion of the bubble 290, the fluid 280 in the pumping chamber 212 is discharged from the pumping chamber 212 to the outlet manifold 216 through the fluid exit 214, during which the pulse-type current signal applied to the heating element 230 is removed.   As the bubble 290 expands, a flow rate of the fluid 280 is generated in a direction toward the inlet manifold 215 via the fluid entrance 213.   In this case, since flux resistance in a direction of gradually increasing cross-sectional area of the fluid passages 213 and 214 is smaller than flux resistance in a direction of gradually decreasing cross-sectional area of the fluid passages 213 and 214, the amount of fluid 280 discharged from the pumping chamber 212 through the fluid exit 214 is much larger than the amount of fluid 280 discharged from the pumping chamber 212 through the fluid entrance 213.

[0065]   Referring to FIG. 7B, when the bubble 280 contracts and finally disappears, pressure affects the pumping chamber 212 in an inward direction from outside the pumping chamber 212 to the inside of the pumping chamber 212 so that the fluid 280 flows into the pumping chamber 212 through both the fluid entrance 213 and the fluid exit 214.   In this case, flux

resistance at the fluid entrance 213 is smaller than flux resistance at the fluid exit 214. Thus, the amount of fluid 280 flowing into the pumping chamber 212 through the fluid entrance 213 is much larger than the amount of fluid 280 flowing into the pumping chamber 212 through the fluid exit 214. As the fluid 280 flows into the pumping chamber 212, heat around the heating element 230 and other elements is dissipated to the substrate 210 or the outside through the heat dissipation layer 270.

[0066] As described above, the micro-pump according to the second embodiment of the present invention provides a similar pumping effect as that of the micro-pump according to the first embodiment of the present invention. In addition, since the micro-pump according to the second embodiment of the present invention does not need a movable element, it is possible to manufacture a micro-pump having a relatively simple structure and enhanced durability, in which a pumping flow rate may be easily enhanced.

[0067] FIGS. 8A through 8C are graphs illustrating characteristics of a micro-pump according to an embodiment of the present invention. More specifically, FIG. 8A is a graph illustrating a variation of an amount of fluid passing through a fluid exit in accordance with a passage of time. FIG. 8B is a graph illustrating a variation of an amount of fluid passing through a fluid entrance in accordance with a passage of time. FIG. 8C is a graph

illustrating a variation of a net flow rate of fluid in accordance with a passage

of time.

[0068]   In experiments having results shown in FIGS. 8A through 8C, the fluid

entrance and the fluid exit are circular-shaped having an average diameter

of 28 μm and a length of 30 μm, and having a decreasing cross-sectional

area in a direction in which fluid is pumped.   In addition, in those

experiments, the variation of the amount of fluid passing through the fluid

entrance or the fluid exit in accordance with the passage of time (s) was

measured while carrying out a 20 kHz pumping process for six cycles, i.e.,

for about 300 μs.   In FIGS. 8A through 8C, a positive amount of fluid

passing through the fluid entrance or the fluid exit represents the volume of

fluid flowing out of a pumping chamber into a manifold, and a negative

amount of fluid passing through the fluid entrance or the fluid exit represents

the volume of fluid flowing into the pumping chamber from the manifold.   In

FIGS. 8A through 8C, $1 \times 10^{-14} m^3$ is equal to 10 pl.

[0069]   Referring to FIGS. 8A and 8B, a time when fluid passes through the

fluid entrance corresponds to a time when fluid passes through the fluid exit,

which correspond to cycles of appearance and then disappearance of

bubbles in the fluid.   However, the amount of the fluid passing through the

fluid entrance is different from the amount of the fluid passing through the

fluid exit.   Here, the sum of the amount of the fluid passing through the fluid

entrance and the amount of the fluid passing through the fluid exit is the amount of the fluid flowing into or flowing out of the pumping chamber through the fluid entrance or the fluid exit. Due to the structure of the fluid entrance or the fluid exit having a cross-sectional area that varies in a direction in which the fluid is pumped, a net flow rate exists along a direction from the fluid entrance to the fluid exit, which is illustrated in the graph of FIG. 8C. As shown in FIG. 8C, as much fluid as about 8 pl moves from the fluid entrance to the fluid exit per cycle. This amount of fluid pumped per cycle may be increased by adjusting a shape and an inclination angle of the fluid entrance and/or the fluid exit. In addition, pumping effects may be maximized by increasing a driving frequency.

[0070]   As described above, in a micro-pump according to the embodiments of the present invention, a fluid can be pumped in accordance with a phase change of the fluid flowing into a pumping chamber. Thus, a micro-pump according to the embodiments of the present invention does not require a movable element to allow fluid to flow. Therefore, according to the present invention, it is possible to realize a micro-pump having. In addition, it is possible to easily enhance a pumping efficiency of a micro-pump of the present invention by increasing an area of a heating element provided at one side of a pumping chamber or by increasing caloric power of the heating element.

[0071]   Exemplary embodiments of the present invention have been

disclosed herein and, although specific terms are employed, they are used

and are to be interpreted in a generic and descriptive sense only and not for

purpose of limitation.   Accordingly, it will be understood by those of ordinary

skill in the art that various changes in form and details may be made therein

without departing from the spirit and scope of the present invention as set

forth in the following claims.